Supplementary Material

1.1 Temperature Index Method (TIM)

Since the TRHR is located in an elevated region, a snowmelt model was necessary to add to the model's setup. There are two approaches to estimate snowmelt water: The energy balance approach (physical-based) and the TIM approach (conceptual-based) (Fazel et al., 2014). HEC-HMS is only equipped with the latter one. The followings can be the major reasons for its common use, which are mentioned by Hock (2003): a) availability of data (i.e. air temperature and precipitation), b) easy interpolation and forecasting of air temperature, c) comparable performance, d) computationally less demanding, and e) simplicity. A general procedure, how TIM works in HEC-HMS for each elevation band, is described in Fig. 1. In HEC-HMS, each subbasin is divided into elevation bands (1 to 10) and each band can be represented as a small subbasin. Numbers of elevation bands are created based on elevation range and the complexity of topography. If the elevation range is large and the topography is complex, the number of bands will be more. In the present study, we used 3–5 elevation bands for each subbasin. The lapse rate must be estimated for the basin. In this region, a lapse rate of -6.0 °C per km was estimated, using regression analysis between temperature and elevation. As described in Fig. 1, temperature, precipitation, and the elevation difference between a gauge location and a band are the main inputs to TIM. Zonal temperature for each band is calculated using the following equation:

$$T_b = T_g + (-LR \times ED) \qquad \textit{Eq. 1}$$

Where, T_b, T_g, LR, and ED are a band's temperature, a gauge temperature, a lapse rate, and an elevation difference between a band and a gauge, respectively.

PX-temperature is one of the important parameters in TIM, which discriminates that precipitation is occurring as rain or snow (William and Fleming, 2010). Jennings et al. (2018) found 1.0 °C as an average PX-temperature for the North Hemisphere, ranging between -0.4–2.4 °C. They also concluded that PX-temperature could be warmer on highly elevated areas such as Tibetan Plateau, where they showed 4.5 °C as PX-temperature. In the present study, we used 1.5 °C as PX-temperature. If the air temperature is greater than PX-temperature, precipitation occurs as rain either on ground surface or on snow cover. When rain falls on snow cover it causes melting of snowpack (wet-melt or rain melt) if rain rate is greater than the specified rain rate limit. In the present study, we used 10 mm/day as a rain rate limit. If air temperature is less than PX-temperature then precipitation occurs as snow.

Snowmelt amount is calculated based on the zonal air temperature, base temperature, and melt rate factor at each time step. If the air temperature is less than the base temperature (0 °C, typically used as base temperature), then the amount of melt is assumed to be zero. Total snowmelt water is the summation of dry-melt, rain-melt, and ground-melt (Fig. 1) (William and Fleming, 2010).

1.2 Soil Moisture Accounting (SMA)

SMA is an advanced continuous and complex method in HEC-HMS to calculate losses and excess rainfall (Bhuiyan et al., 2017). It simulates the movement of water over time through a set of storage zones in the groundwater and soil profile layers (William et al., 2010). SMA-algorithm in HEC-HMS represents the watershed with five layers, as shown in Fig. 2, which requires 13 parameters (i.e., surface depression storage, canopy interception storage, soil storage, infiltration rate, tension zone storage, soil percolation rate, storage depth, and storage coefficient and percolation rate for shallow and deep groundwater layers) to estimate during the calibration process.

SMA takes precipitation as its input and routes it through the canopy storage (canopy method described below in detail), and then it is combined with available surface water storage (Samady, 2017). If this combination exceeds the potential infiltration capacity of the soil profile, the excess volume will become surface runoff. Soil storage is then filled with the infiltrated water volume. The soil storage zone is divided into two parts—upper zone and tension zone storage (Gyawali and David, 2013). Precipitation can percolate from the upper zone, but not from the tension zone, into the groundwater layer 1 (GS1). The percolated water into GW1 is routed as baseflow, while the remaining water leaches into the deeper groundwater layer (GW2). The water in GW2 then percolates down to a deep aquifer (basically lost from the system), and the surplus water in GW2 is routed as baseflow (Samady, 2017). The routed water from GW1 and GW2 is transformed to streamflow based on the characteristics of the reservoir, and then it is routed to the basin outlet. The number of groundwater storage layers can be reduced to one by putting the storage coefficient of GW2 equal to zero. In this case, only one groundwater storage layer (GW1) will provide water to the LRBM, which will route storage water as baseflow (described below in detail). The model does not track precipitation and evapotranspiration simultaneously (Bennett and Peters, 2000). First, it routes precipitation through the system, and then evapotranspiration is computed only if the water is present in the canopy, surface, and/or tension zones, when precipitation is not occurring. SMA first calculates the evapotranspiration from canopy storage, then the surface storage. If potential evapotranspiration is not satisfied by the first two storage components, the algorithm removes the water from tension zone storage. The water removal from the tension zone occurs at a slower pace based on the maximum storage capacity of the tension zone and the depth of the soil storage (Samady, 2017; William et al., 2010).

1.3 Linear reservoir, Clark unit hydrograph, and canopy modules

The LRBM, which is used in conjunction with SMA, simulates the storage and movement of subsurface flow as storage and movement of water through reservoirs. An outflow from the GW1 of SMA is an inflow to the first linear reservoir, and an outflow from the GW2 of SMA is an inflow to the second linear reservoir. The sum of outflows from both reservoirs is the total baseflow for the watershed. There are only two groundwater storage layers in the present version of HEC-HMS-v4.3. We used one reservoir in the present study for each groundwater storage layer (Feldman, 2000; Samady, 2017; William et al., 2010). The CUH transforms excess precipitation obtained from SMA into direct surface runoff. It is a synthetic unit hydrograph method and has two parameters (storage coefficient and time of concentration) to optimize during calibration. Lastly, the surface flow is transferred from one point to another using the Muskingum method, which is a simple mass conservation scheme for routing flow through the channels (William et al., 2010).

The canopy module is a very important component during continuous simulation modeling and is an essential part of SMA. It intercepts precipitation, which evaporates into the atmosphere, and reduces the amount of precipitation falling directly on the ground surface (Samady, 2017). Another important process that is done by vegetation is transpiration, in which plants extract water from the soil through roots (Sánchez-Carrillo et al., 2001). There are two canopy methods in HEC-HMS i.e., a Simple and a Dynamic Canopy. In Simple Canopy, crop coefficients for each subbasin are temporally same (i.e., same for every day) and can be same spatially. Mostly 0.7 value is used as a crop coefficient in HEC-HMS in the simple canopy. On the other hand, in Dynamic, a crop coefficient varies spatially as well as temporally (William and Fleming, 2010). In the present study, we used the Dynamic Canopy. For this, crop coefficients were estimated from Leaf Area Index

obtained from *Global Monthly Mean Leaf Area Index (LAI) Climatology, 1981–2015*(Mao and Yan, 2019), using the following equation, described in (Corbari et al., 2017):

$$Kc_{FAO} = Kc_{min} + (Kc_{max} - Kc_{min})[1 - e^{-0.7LAI}] \qquad \textit{Eq. 2}$$

$$Kc_{max} = Kc_h + [0.04(\overline{u_2} - 2) - 0.004(RH_{min} - 45)]\left(\frac{h}{3}\right)^{0.3} \qquad \textit{Eq. 3}$$

$$Kc_h = 1 + 0.1h \qquad \textit{Eq. 4}$$

Where Kc_{FAO} is the crop coefficient of natural vegetation, and Kc_{min} and Kc_{max} are the minimum and maximum values of crop coefficients. $\overline{u_2}$ and RH_{min} are mean wind speed and mean min relative humidity and h is the mean height of vegetation.

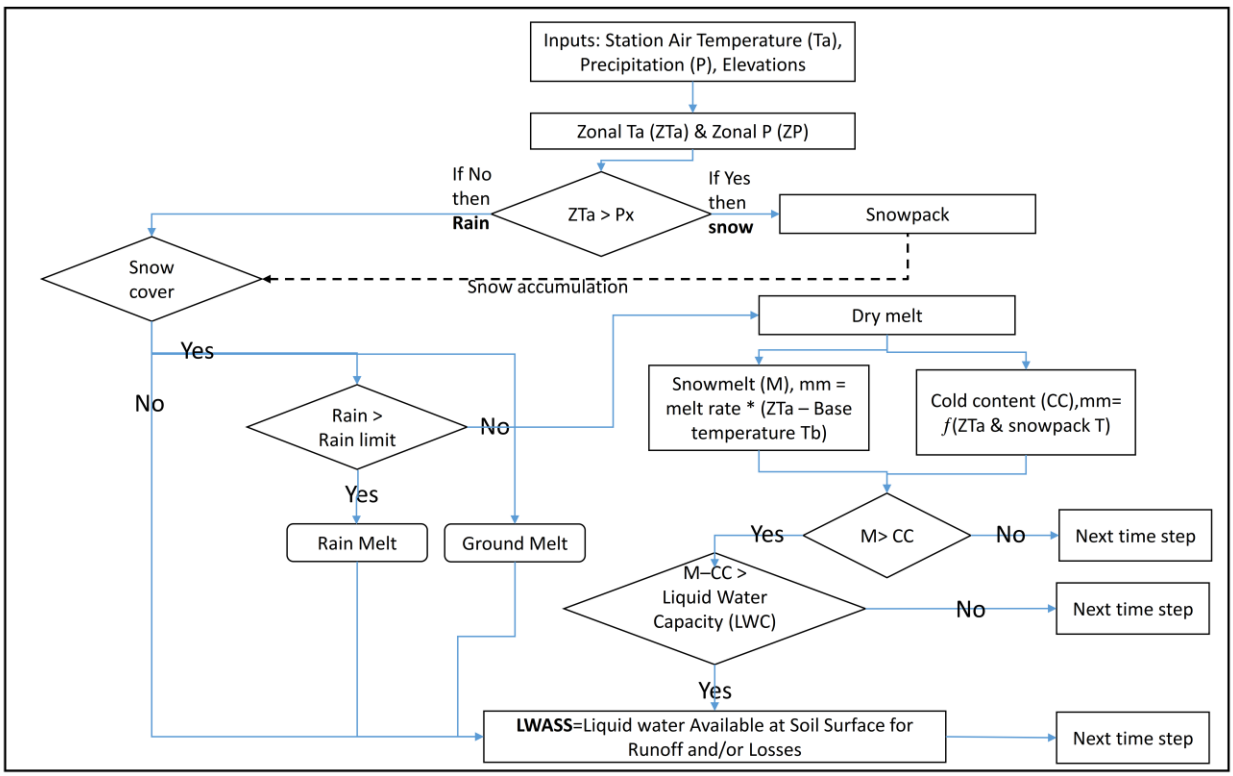

Figure S1. Schematic diagram of Temperature Index method in HEC-HMS. PX-temperature discriminates between rain and snow. Cold content (mm w.e.) is calculated based on air temperature and snowpack temperature. Liquid Water Capacity (LWC) is the amount of melted

water that stores in the snowpack before liquid water becomes available at the ground surface for runoff or infiltration.

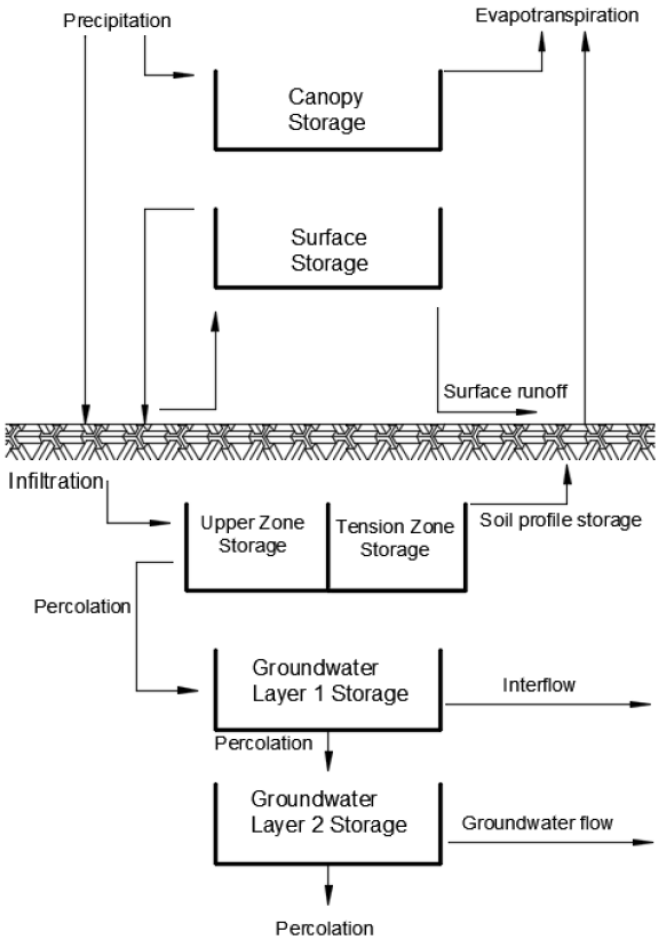

Figure S2. Schematic diagram of soil moisture accounting algorithm in HEC-HMS adopted from (Feldman, 2000).

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